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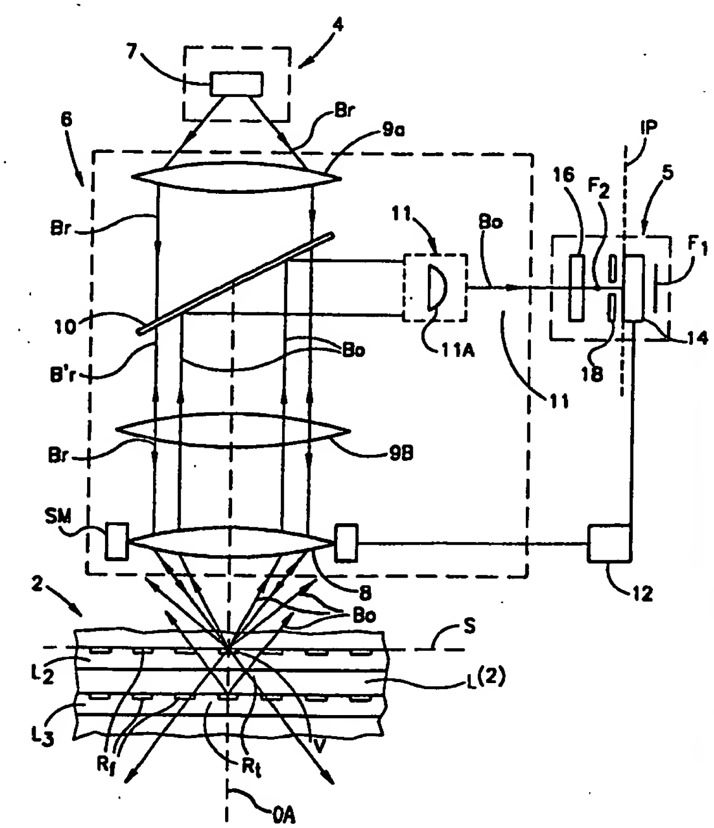
(57) Abstract

A focus error correction apparatus for use in a pickup system for reading data in a three-dimensional information carrier is presented. The information carrier is formed with a plurality of spaced-apart data regions, each surrounded by surrounding regions. The data regions are made of a material capable of generating an output excited radiation, when interacting with a predetermined incident exciting radiation. The surrounding regions are substantially optically transparent with respect to the incident and output radiation. A focusing optics defines a focal plane inside the carrier, and is associated with an actuator that provides a relative displacement between the information carrier and the focusing optics along its optical axis. A filter assembly picks up the output radiation to be received by a detection unit. An arrangement is provided for defining at least two spaced-apart focal planes aligned in a preset relationship with the focal plane of the focusing optics, such that the received output radiation is indicative of the relative location of the addressed plane relative to the focal plane.



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Focus Error Correction Apparatus

FIELD OF THE INVENTION

This invention is in the field of optical reading techniques, and relates to a focus error correction apparatus used with a reading system for reading in high-density optical data storage devices, such as compact discs (CDs), tapes, cards, or the like.

BACKGROUND OF THE INVENTION

Two-dimensional optical memory devices are known and widely used as high-density and high-capacity storage medium. They typically comprise one information-carrying layer formed with a pit-like pattern.

Three-dimensional optical memory devices have been developed for significantly increasing the amount of recorded data, in comparison to that of two-dimensional devices. The capacity of a three-dimensional optical memory device is proportional to the third order of a reading radiation wavelength. For example, the total thickness of a three-dimensional optical memory device can be of 1mm, and can be formed of information layers having a thickness of 0.01mm. The storage capacity of such a device is 100 times greater than the capacity of a single layer.

A three-dimensional optical memory device is disclosed, for example, in U.S. Patent No. 4,090,031. The device comprises a substrate and a plurality of data layers provided on one side of the substrate. Each of the data layers comprises data tracks formed of lines of data spots. In this device, similar to the conventional two-dimensional one, information

carrying pit-like regions, as well as the adjacent regions of the layers, are light reflective. Consequently, conventional reading techniques are based on interference/reflectivity physical principles. In order to select one data layer for playback, the focus of a reading light beam is changed from one data layer to another utilizing a focus error correction technique, which typically employs control electronics and a servo motor for driving an objective lens.

One example of a focus-error correction apparatus used in a reading system for reading a radiation-reflecting record carrier is disclosed, in U.S. Patent No. 4,123,652. Here, the focus error detection is based on the use of astigmatic optics. However, since the data layers are substantially reflective, an unavoidable multiple reflection occurs, which impedes the reading in such a "reflective" information carrier having more than two data layers.

Three-dimensional optical memory devices based on fluorescent data regions, rather than reflective, are disclosed in U.S. Patent Applications Nos. 08/956,052 and 08/944,402 assigned to the assignee of the present application. Unfortunately, the conventional focus-error correction techniques used for reading in the "reflective" information carrier are not effective for a three-dimensional "fluorescent" information carrier.

SUMMARY OF THE INVENTION

There is accordingly a need in the art to improve the conventional focus-error correction techniques by providing a novel focus-error correction apparatus to be used with a reading system for reading in a three-dimensional information carrier.

The main idea of the present invention is based on the following. A three-dimensional information carrier is formed with a plurality of spaced-apart data regions surrounded by surrounding regions. The data regions are made of a material capable of generating output excited radiation, when interacting with a predetermined incident exciting radiation.

The surrounding regions are substantially optically transparent for both the incident exciting and output excited radiation.

The predetermined incident radiation is directed onto an addressed plane inside the carrier, and produces the output excited radiation, when interacting with the data regions located in the optical path of the incident radiation. The same focusing optics focuses the incident radiation and collects the output radiation. A suitable filter assembly picks up the output radiation to be received by a detection unit. The focus error correction technique utilizes an arrangement that defines at least two spaced-apart focal planes aligned in a preset relationship with a focal plane of the focusing optics. As a result, the output radiation reaching the detection unit is indicative of the relative location of the addressed plane relative to the focal plane of the focusing optics. This information is used for focus error detection and adjustment of the position of the focusing optics, so as to locate the addressed plane in the focal plane.

There is thus provided, according to one aspect of the present invention, a focus error correction apparatus for use in a pickup system for reading data in a three-dimensional information carrier formed with a plurality of spaced-apart data regions surrounded by surrounding regions, wherein the data regions are made of a material capable of generating an output excited radiation, when interacting with a predetermined incident exciting radiation, and the surrounding regions are substantially optically transparent for the incident and output radiation, the apparatus comprising:

(a) an illumination unit generating said predetermined incident radiation which is directed onto an addressed plane inside the carrier and produces said excited output radiation;

(b) a detection unit having a radiation-sensitive surface for receiving said output radiation and generating data representative thereof;

(c) a focusing optics defining a focal plane inside the carrier;

(d) an actuator providing a relative displacement between the information carrier and the focusing optics along an optical axis thereof;

(e) a filter assembly for picking up said output radiation to be received by the detection unit;

(f) an arrangement defining at least two spaced-apart focal planes aligned in a preset relationship with said focal plane of the focusing optics, said received output radiation being indicative of the location of the addressed plane relative to said focal plane; and

(g) a control unit coupled to the detection unit and to the actuator, the control unit being responsive to said data representative of the received output radiation for determining the relative position of the addressed plane, and generating a focus error correction signal to operate the actuator accordingly.

Preferably, the filter assembly comprises a spectral filter that allows the passage of the output radiation to the detector radiation-sensitive surface and prevents any other radiation spectrum from reaching the detector. Preferably, the filter assembly also comprises a beam splitter separating the output radiation and directing it to the detection unit.

The material capable of generating the excited output radiation comprises a fluorescent component. The output radiation is fluorescence excited in the recording regions interacting with the incident radiation.

According to one embodiment of the invention, the arrangement defining the at least two focal planes comprises an astigmatic element accommodated in the optical path of the separated output radiation.

According to another embodiment of the invention, the arrangement defining the at least two focal planes comprises an optical assembly for splitting the incident radiation into at least three spatially separated beams and focusing one of them onto said focal plane of the focusing optics and the at least two other beams on said at least two focal planes. Preferably, the optical assembly comprises a holographic plate accommodated in the

optical path of the incident radiation upstream of the focusing optics. Hence, the output radiation is composed of at least three spatially separated components. To this end, the detection unit comprises three separate detectors, each for receiving a corresponding one of the output radiation components. The detectors are spaced a certain predetermined distance from each other along an axis of propagation of the output radiation.

According to yet another embodiment of the invention, the arrangement defining the at least two focal planes comprises a driver associated with the focusing optics for providing continuous oscillation thereof along its optical axis. In this case, the detection unit may comprise an aperture accommodated in front of the radiation-sensitive surface. The diameter of the aperture is substantially equal to the dimensions of the recording region. For this purpose, a modulation-sensitive electronics is provided, associated with either the detection or control unit.

The information carrier may be such that each of the recording regions comprises a material substantially reflective with respect to said incident radiation. This reflective material is located underneath the fluorescent material, so as to produce a reflected light component coming out of the information carrier. In this case, the detection unit preferably comprises a first detector that defines the radiation-sensitive surface and a second detector. The first and second detectors receive, respectively, the first, output fluorescent radiation and the second, reflected radiation. Consequently, the filter assembly comprises a dichroic mirror for separating the fluorescent radiation and directing it onto the first detector, and a partially transparent mirror for separating the reflected radiation and directing it onto the second detector. The control unit may be coupled to the second detector and to the actuator, in which case the first detector receives the fluorescent radiation and generates data representative of the information stored in the information carrier.

According to another aspect of the present invention, there is provided a pickup system for reading information stored in a three-dimensional information carrier, which is formed with a plurality of spaced-apart data regions, each surrounded by surrounding regions, wherein the data regions are made of a stack formed by an upper fluorescent material and a lower reflective material with respect to a predetermined incident radiation, thereby producing a first, fluorescent output radiation and a second, reflected output radiation, when interacting with said incident radiation, the surrounding regions being substantially optically transparent, the system comprising:

(i) an illumination unit generating said predetermined incident radiation which is directed onto an addressed plane inside the carrier;

(ii) a focusing optics accommodated in optical path of the incident and output radiation and defining a focal plane inside the carrier;

(iii) a first detection unit for receiving said first radiation component and generating data representative of the information stored in the carrier;

(iv) a first radiation splitting means for separating the first radiation component and directing it to the first detection unit;

(v) a second detection unit for receiving said second radiation and generating data representative thereof;

(vi) a second splitting means for separating said second radiation and directing it to the second detection unit;

(vii) an actuator providing a relative displacement between the information carrier and the focusing optics along an optical axis thereof;

(viii) an arrangement defining at least two spaced-apart focal planes aligned in a preset relationship with said focal plane of the focusing optics, said received second radiation being indicative of the relative location of the addressed plane relative to the focal plane; and

(ix) a control unit interconnected coupled to the second detection unit and to said actuator, the control unit being responsive to said data representative of the received second radiation for determining said relative location, and generating a focus error correction signal to operate the actuator accordingly.

BRIEF DESCRIPTION OF THE DRAWINGS:

In order to understand the invention and to see how it may be carried out in practice, a preferred embodiment will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

Fig. 1 is a block diagram illustrating the main components of a focus error correction apparatus according to one embodiment of the invention, associated with an information carrier constructed according to one example of the invention;

Figs. 2a and 2b show the main principles underlying the implementation of the information carrier of Fig. 1;

Figs. 3a to 3d illustrate the main principles of a focus error detection technique utilized in the apparatus of Fig. 1;

Figs. 4a and 4b illustrate the principles of the focus error detection technique applied to the carrier shown in Figs. 2a and 2b, as compared to the conventional "reflective" information carrier;

Figs 5 and 6 illustrate two more embodiments of a focus error correction apparatus according to the invention;

Figs. 7a and 7b illustrate the main principles of a focus error correction technique according to yet another embodiment of the invention;

Fig. 8 schematically illustrates another example of an information carrier; and

Fig. 9 is a block diagram of a reading system suitable for reading in the information carrier of Fig. 8, utilizing a focus error correction technique according to the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to Fig. 1, there is illustrated a focusing apparatus, generally designated **1**, which is a constructional part of a pickup system (not shown) for reading in an information carrier **2**. The apparatus **1** comprises an illumination unit **4**, a detection unit **5**, radiation directing optics **6** and a control unit **12**.

The illumination unit **4** includes a radiation source **7** that generates a reading beam $\mathbf{B_r}$ of a predetermined wavelength λ_r. The radiation directing optics **6** typically includes an objective lens **8** or a plurality of such lenses (constituting a focusing optics), an auxiliary lens **9a** and a spherical aberration corrector **9b**. Further provided with the light directing optics **7** are a beam splitter **10** and an imaging optics **11** including a cylindrical lens **11a** (constituting an astigmatic element). The objective lens **8** is supported for sliding movement along its optical axis **OA** towards and away from the carrier **2** by means of an appropriate servomechanism, generally at **SM**. It should be noted, although not specifically shown, that a suitable drive means is provided for driving the rotation of the carrier **2** about its axis, and a reciprocating movement of the carrier with respect to the objective lens **8** so as to effect scanning of the addressed plane inside the carrier.

The reading beam $\mathbf{B_r}$ impinges onto the data carrier **2**, illuminating a spot **V** located in a plane **S** inside the carrier **2**, and produces an output radiation $\mathbf{B_o}$ of a certain wavelength range λ_o, as will be described specifically further below. The optics **6** directs the incident radiation and returned radiation towards and away from the carrier **2**, respectively. The beam splitter **10** is a dichroic mirror substantially optically transparent for the incident radiation spectrum λ_r, and substantially reflective for the output

radiation spectrum λ_0. In other words, the beam splitter **10** separates the incident and output beams B_r and B_o, respectively, and directs the output beam B_0 towards the detection unit **5**.

The detection unit **5** comprises a radiation sensitive detector **14** equipped by an optical filter **16**, and is optionally provided with an aperture stop **18**. The aperture stop **18** serves for collecting only a part of the output radiation propagating towards the detector **14**. The filter **16** prevents any radiation component within a spectrum other than that of the output radiation λ_o from reaching the detector **14**. The detector **14** is of a known kind defining a radiation-sensitive surface **IP** for receiving light signals and generating data representative thereof. The electronic unit **12** is interconnected between the servomechanism **SM** and the detector **14**. The control unit is provided with suitable hardware and operated by suitable software so as to be responsive to the data representative of the received light for determining a displacement of the plane **S** from the focal plane of the lens **8** and generating a so-called "focus-error correction signal". This signal operates the mechanism **SM** to move the lens **8** accordingly so as to position its focal plane in the addressed plane **S**.

Reference is now made to Figs. 2a and 2b, which illustrate more specifically the construction of the information carrier **2**. The carrier **2** comprises several information layers, for example three layers L_1, L_2 and L_3, formed on a substrate **22** in a spaced-apart parallel relationship. Each two adjacent information layers are spaced by intermediate layers $L^{(1)}$ and $L^{(2)}$, respectively. The substrate **22** and intermediate layers $L^{(1)}$ and $L^{(2)}$ are made of an optically transparent material for both the incident radiation λ_r and the output radiation λ_o. The information layers L_1-L_3 comprise regions or pits, generally at R_f, filled with a fluorescent material and surrounded by regions R_t that are made of the same optically transparent material as that of the substrate and intermediate layers. Hence, the regions R_f represent

recording fluorescent regions, while the surrounding regions R_t of the information layer, as well as the substrate and intermediate layers, constitute together the optically transparent surrounding regions of the carrier **2**.

Each fluorescent region R_f represents a radiation source emitting an output fluorescent radiation induced by its interaction with an appropriate incident radiation. In order to successfully read-out the recorded information from the information carrier **2**, the following conditions should be satisfied. The recording regions, substantially non-transparent and non-reflective, occupy approximately 10-20% of the total layer area, while the remaining 80-90% of the layer is substantially optically transparent. The absorption of recording regions with respect to the incident reading radiation should preferably be in the range of 5-50%. When reading from such a device, the absorption of the information layer for non-focused reading light is about 1-10%, which is by order of magnitude less than the absorption of the reading light focused on the recording regions. A significant part of the absorbed reading radiation is associated with the recording region located in the focus of the radiation directing optics. A relatively non-significant part of the absorbed reading radiation is associated with a plurality of the recording regions located in the optical path of the reading beam out of focus of the directing optics, this part being distributed over all the recording regions. Hence, the fluorescence of any in-focus recording region is much stronger (about 1000 times) than that of any out-of-focus recording region.

Owing to the fact that the recording regions R_f are constructed as described above and surrounded by the transparent regions R_t, there is no strict limitation to the height of the recording regions. This enables the recorded data contained within the carrier to be significantly increased by desirably varying the height of the recording regions. Consequently, this enables making each of the recording regions of a minimum possible length, and therefore making more such regions within each information layer.

The apparatus **1** operates in the following manner. For example, the information is to be currently read from the information layer $\mathbf{L_2}$ and, therefore, the reading beam $\mathbf{B_r}$ should be focused onto this layer. The propagation of light beams is shown schematically in order to facilitate the illustration. The reading beam $\mathbf{B_r}$ passes through the information layer $\mathbf{L_1}$ and intermediate layer $\mathbf{L^{(1)}}$, which are, respectively, 80-90% transparent and totally transparent, and successfully impinges onto the desired layer $\mathbf{L_2}$ illuminating the spot **V**. The incident radiation $\mathbf{B_r}$ is within such a wavelength range λ_r as to excite, when interacting with the recording regions $\mathbf{R_f}$, the fluorescence of that specific fluorescent material used in the carrier **2**, producing the excited fluorescent radiation $\mathbf{B_o}$.

The objective lens **8** collects light returned from the carrier **2** and directs it to the dichroic mirror **10**. The collected light is composed of the output fluorescence $\mathbf{B_o}$ excited in all recording regions located in the optical path of the incident beam $\mathbf{B_r}$, i.e. before-, in- and after the addressed layer, and a relatively small light component $\mathbf{B'_r}$ that may be reflected from the surrounding regions $\mathbf{R_t}$. The dichroic mirror **10** reflects the fluorescent radiation $\mathbf{B_o}$, which is thus delivered to the detection unit **5**, and transmits the reflected light component $\mathbf{B'_r}$ away from the detection unit **5**. Some of the fluorescence $\mathbf{B_o}$ reaching the detection unit **5** is rejected by the aperture stop **18**, while some of the non-fluorescent radiation, which may propagate towards the detection unit **5**, is rejected by the filter **16**.

As indicated above, the recording region $\mathbf{R_f}$ represents a fluorescent radiation source. Therefore, fluorescent signals detected by the detector **14** do not depend on the optical path of the incident radiation, and rather depend only on the distance between the plane **S** (addressed layer $\mathbf{L_2}$) and the objective lens **8**.

It is known that an astigmatic element typically has two focal lines which, being viewed in an axial direction, occupy different positions and are perpendicular to each other. Thus, the objective lens **8** and cylindrical

lens **11** add two focal lines $\mathbf{F_1}$ and $\mathbf{F_2}$ to the read spot **V**. The relationship between the lines $\mathbf{F_1}$ and $\mathbf{F_2}$ and the **X-Y** coordinate system is clearly illustrated in Fig. 3a. When the distance ***d*** between the illuminated layer $\mathbf{L_2}$ and the objective lens **8** is shorter than the lens focus ***f*** (i.e. $d<f$), the dimensions of the spot **V** become larger than the dimensions of the region $\mathbf{R_f}$. In this case, notwithstanding that the dimensions of the region $\mathbf{R_f}$ remain unchanged, the dimensions of the imaged spot **V'** in the imaging plane **IP** defined by the sensing surface of the detector **14** will be increased. When the distance ***d*** between the illuminated layer $\mathbf{L_2}$ and objective lens **8** is larger than the lens focus ***f*** (i.e. $d>f$), the illuminated spot size **V** becomes larger than the region $\mathbf{R_f}$ size, but oriented differently in comparison to that of the opposite situation. In this case, the position of the fluorescent radiation source is larger than that of the in-focus position, relative to the objective lens **8**. Figs. 3b-3d illustrate three different shapes and orientations of the imaging spot **V'**, corresponding respectively to before-, in- and after-focus positions of the addressed layer $\mathbf{L_2}$.

In order to determine the focus position relative to the desired layer and to operate the servomechanism **SM** accordingly, the so-called "focusing signal" is determined from the detected fluorescent signal. To this end, the detector **14** is typically a so-called "quadrant-cell" comprising four sub-detectors $\mathbf{D_1}$, $\mathbf{D_2}$, $\mathbf{D_3}$ and $\mathbf{D_4}$ which are disposed in the individual quadrants of an **X-Y** coordinate system. Each of the sub-detectors is exposed to a corresponding fluorescent component, and generates data representative thereof. The focusing signal is calculated from these data in a conventional manner. A so-called "focus-correction signal" is derived electronically from the focusing signal, and the objective lens **8** is moved accordingly, so as to locate the plane **S** (layer $\mathbf{L_2}$) in the focus of the lens **8**.

Turning now to Figs. 4a and 4b, the focusing signal is proportional to the distance **z** between a point **A**, located in a focal plane **FP** of the lens (not shown), and a source of that detected radiation **A'** which is projected onto

the imaging plane **IP**. As shown in Fig. 4a, according to the conventional technique associated with the "reflective" information carrier, such a source of the detected radiation **A'** is an image of the focal point **A** produced in accordance with the known laws of reflection. Hence, the distance z is equal to $2h$, wherein **h** is the distance between the focal point A and the addressed layer $\mathbf{L_2}$. Fig. 4b shows that according to the present invention, the distance z is equal to h. It is evident that owing to the absence of interference and diffraction effects in the information carrier **2**, the focus error correction technique according to the invention has less requirements to the optical arrangement, as compared to that used in the conventional apparatus associated with the "reflective" carrier.

Fig. 5 illustrates a focus error detection apparatus, generally designated **100**, constructed according to another embodiment of the invention. The apparatus **100** is suitable for reading in the information carrier **2**. Those components, which are identical in the devices **1** and **100**, are identified by the same reference numbers in order to facilitate understanding. The astigmatic element **11a** of the apparatus **1** is replaced here by a driver **24** coupled to the servomechanism **SM** for providing a continuous oscillation of the lens **8** along its optical axis **OA**. Obviously, the implementation may be such that the servomechanism carries out the function of the driver **24**.

The illumination unit **4** generates a beam of the incident radiation $\mathbf{B_r}$ of a predetermined wavelength λ_r, selected to excite the fluorescent material contained in the recording regions $\mathbf{R_f}$. The incident beam $\mathbf{B_r}$ passes through the light directing optics **6** and impinges onto the carrier **2** producing the output fluorescent radiation $\mathbf{B_o}$. Some light component of the incident radiation may be reflected from the surrounding regions $\mathbf{R_t}$, resulting in the reflected radiation component $\mathbf{B_r}$'. The fluorescent and reflected light components $\mathbf{B_f}$ and $\mathbf{B_r}$' are collected by the lens **8** and then, respectively, reflected and transmitted by the dichroic mirror **10**.

It is understood that the amount of the collected fluorescent radiation B_0 is proportional to the intensity of reading radiation B_r interacting with the recording regions. The intensity of reading radiation reaches its maximum at the focus of the lens **8**. Consequently, the detected fluorescent signal reaches its maximum value when the focal plane substantially coincides with the fluorescent regions containing layer. As shown, locations **A** and **B** are aligned along the optical axis **OA** of the lens **8** being, respectively, below and above the addressed information layer L_2. If the reading beam B_r is focused onto either of the locations **A** or **B**, the detected fluorescent signal will be less than the maximum value. The reduction of the detected signal during the movement of the lens **8** towards the surface of the carrier **2** indicates that the information layer is located between the lens **8** and its focal plane. This is immediately detected by the electronic unit **12**, and subsequently the position of the lens **8** is adjusted accordingly, so as to locate the desired information layer in the focus of the lens. Such a multi-layer information carrier **2** has the layers' addressed information written in the information layers. Reading of a specific layer provides information about the layer number. This information is used for moving the lens **8** in the direction of the desired layer. It should be noted, although not specifically shown, that in a reading system, various elements can be used to provide the above described focus-error corrections. For example, holographic optics can combine most of the above optical functions, e.g. lenses, beam splitter.

Reference is made to Fig. 6, illustrating yet another example of a focus error correction apparatus, generally designated **200**, associated with the information carrier **2**. An illumination unit **26** is designed so as to generate three separate beams of reading radiation, generally at Br_1, Br_2 and Br_3. To this end, although being not specifically illustrated, the illumination unit **26** may comprise three light sources for emitting three separate beams, or a single light source and suitable beam splitting means. A holographic

plate **27** is located in the optical path of the incident beams $\mathbf{Br_1}$, $\mathbf{Br_2}$ and $\mathbf{Br_3}$ so as to focus the beams onto different locations **A**, **B** and **C**, which are aligned along the optical axis **OA** of the lens **8** below, above and in the information layer $\mathbf{L_2}$, respectively. A detection unit **28** of the apparatus **200**, in distinction to that of the apparatus **1**, comprises three separate detectors **14a**, **14b** and **14c** provided with apertures **18a**, **18b** and-**18c**, respectively.

The interaction of the incident beams $\mathbf{Br_1}$, $\mathbf{Br_2}$ and $\mathbf{Br_3}$ with the carrier **2** results in the provision of three separate output fluorescent radiation components, $\mathbf{Bo_1}$, $\mathbf{Bo_2}$ and $\mathbf{Bo_3}$, which are delivered to the detection unit **28**. The dichroic mirror **10** and filter **16** would prevent any non-fluorescent radiation component from reaching the detectors **14a-14c**. The fluorescent radiation reflected from the dichroic mirror **10**, propagates towards the detection unit **28** along an axis **OP**. The detectors **14a-14c** are accommodated in the optical path of the propagation of the fluorescent radiation, and are spaced-apart from each other a corresponding distance (i.e. corresponding to that between the points **A**, **B** and **C**) along the axis **OP**. Signals detected by the detectors **14a** and **14b** (i.e. associated with the locations **A** and **B**) are equal, being less than that detected by the detector **14c** (i.e. associated with the location **C**). According to the present example of Fig. 6, the separate detectors **14a-14c** carry out the focus-error detection (i.e. out-of-focus position of the location **C**). When the carrier **2** moves up (i.e. closer to the lens **8**), the fluorescent signals coming from the locations **A** and **B** decrease and increase, respectively. The difference has opposite signs when the focal plane of the lens is below and above the desired layer $\mathbf{L_2}$. The control unit **12** is responsive to the detected signals for operating the servomechanism **SM** accordingly.

Reference is now made to Figs. 7a and 7b, showing the main principles of a focus error detection technique according to yet another embodiment of the invention. A focus error correction apparatus, generally designated **300**, is generally similar to the apparatus **100**, and the focus error

detection technique utilizes the oscillation of the objective lens **8** along its optical axis **OA**. In the apparatus **300**, in distinction to the apparatus **100**, a radiation source **29** generates a non-coherent incident beam $\mathbf{B_r}$, and a detection unit comprises modulation-sensitive electronics, generally at **30**, which is coupled to the detector **14** or is integral either with the detector or with the control unit **12**. An illuminated area (not shown) is defined by the spacing between the adjacent information layers and angular field of view (numerical aperture) of the objective lens **8**. To this end, the diameter **D** of the aperture stop **18** is defined by the dimensions of the recording region $\mathbf{R_f}$, such that an imaging spot occupies the entire aperture, and no surrounded regions $\mathbf{R_t}$ are projected onto the detector **14**.

Different distributions of the output fluorescent signal $\mathbf{B_o}$ in a plane defined by the radiation-sensitive surface **IP** of the detector **18** are shown. Intensity distributions $\mathbf{I_0}$ and $\mathbf{I_1}$ are associated with the information layers located, respectively, in and out of focus of the lens **8**. The difference in the intensities distribution is caused by the fact that the recording fluorescent regions $\mathbf{R_f}$ occupy only a small fraction (about 10-20%) of the information layer. The only light component collected by the diameter **D** of the aperture **18** passes towards the detector **14**. The amount of the fluorescent radiation $\mathbf{B_o}$ impinging onto the radiation-sensitive surface of the detector **14** reaches its maximum value when the information layer is located in the focus of the lens **8**. The intensity distribution $\mathbf{I_0}$ is transformed into the distribution $\mathbf{I_1}$, when the addressed information layer moves out of focus, and, therefore, the detected signal is reduced. This is detected by modulation-sensitive electronics **30**. The fluorescent signal is further reduced with the movement of the addressed layer away from the focal plane. The oscillation of the lens **8** along its optical axis provides variations of the detected signals and, therefore, the position of the desired information layer can be defined for the purpose of focus error corrections.

Turning now to Fig. 8, there is illustrated a part of an information carrier, generally designated **102**, having a somewhat different construction in comparison to that of the carrier **2**. Recording regions, generally $\mathbf{R_f}$', in distinction to those of the carrier **2**, are in the form of stacks comprising three layers, **32a**, **32b** and **32c**, formed of materials having different optical properties. The layers **32a** and **32b** are formed of substantially fluorescent and reflective materials, respectively, with respect to the incident radiation. The layers **32a** and **32b**, when illuminated by appropriate incident radiation, produce excited fluorescent and reflective output radiation, respectively. The layer **32c** is formed of a substantially absorbing material, thereby eliminating an undesirable cross-talk between the adjacent recording regions.

Fig. 9 schematically illustrates a reading apparatus, generally at **400** for reading information stored in the information carrier **102**. Similarly, the same reference numbers identify those components of the apparatus **400**, which are identical with the previously described devices. The apparatus **400** comprises an additional detection unit **34** and a beam splitter **36**. The beam splitter **36** is a partially transparent mirror. The detection unit **34** comprises a suitable optics (not shown), a filter **37** and a detector **38**. The filter **36** allows the passage of the incident radiation spectrum only, and prevents any other radiation component from reaching the detector **48**. According to the present example, a focus error detection technique is based on the use of an astigmatic element **11a**. Alternatively, although not specifically shown, the focus error detection may be carried out in the manner described above with references to either of Figs. 5 or 6.

Reading in the optical memory device **102** is based on the following. The layers **32b** serve as mirrors attached to each fluorescent layer **32a**. Therefore, when the reading radiation $\mathbf{B_r}$ impinges onto the recording region $\mathbf{R_f}$', a small component of the reading radiation is reflected from the layer **32b** and propagates up, together with the fluorescent radiation $\mathbf{B_0}$

excited in the layer **32a**. The reflected and fluorescent light components $\mathbf{B'_r}$ and $\mathbf{B_0}$ are collected by the objective lens **8** and, respectively, transmitted and reflected by the dichroic mirror **10**. The reflected fluorescent radiation component $\mathbf{B_0}$ propagates towards the detection unit **5**. The transmitted radiation $\mathbf{B'_r}$ impinges onto the mirror **36** and, being reflected therefrom, propagates towards the detection unit **34** through the astigmatic element **11a**

The small, reflected light component $\mathbf{B'_r}$ forms a concentrated diffraction limited spot, similarly to that in conventional "reflective" optical memory devices. The position of the illuminated spot can be detected and used for focus error correction, when the focus error is more than the track pitch. The focus error correction technique, in distinction to the conventional one, is based on that no reflection of the concentrated light can be observed at small focus error distances. The recording regions are too small to reflect the concentrated light, taking into account that a single region has dimensions below the diffraction limit, as indicated above. Only diffraction and scattering are observed in this situation. Diffracted and scattered light is used for small focus error corrections when the distance between the information layer and the focus of the reading beam is about one micrometer. In this situation, such fluorescent-reflective recording regions $\mathbf{R'_f}$ act as a virtual source for the reading purposes. When the focus error distance is close to the dimensions of the recording region, the focus error detection techniques described above with reference to Figs. 1, 5 and 6 can be employed for reading the information from the device **102**.

Those skilled in the art will readily appreciate that various modifications and changes may be applied to the preferred embodiment of the invention as hereinbefore exemplified without departing from its scope defined in and by the appended claims.

CLAIMS:

1. A focus error correction apparatus for use in a pickup system for reading data in a three-dimensional information carrier formed with a plurality of spaced-apart data regions, each surrounded by surrounding regions, wherein the data regions are made of a material capable of generating an output excited radiation, when interacting with a predetermined incident exciting radiation, and the surrounding regions are substantially optically transparent with respect to the incident and output radiation, the apparatus comprising:

(a) an illumination unit generating said predetermined incident radiation which is directed onto an addressed plane inside the carrier for producing the excited output radiation;

(b) a detection unit having a radiation-sensitive surface for receiving said output radiation and generating data representative thereof;

(c) a focusing optics defining a focal plane inside the carrier;

(d) an actuator providing a relative displacement between the information carrier and the focusing optics along an optical axis thereof;

(e) a filter assembly for picking up said output radiation to be received by the detection unit;

(f) an arrangement defining at least two spaced-apart focal planes aligned in a preset relationship with said focal plane of the focusing optics, said received output radiation being indicative of the relative location of the addressed plane relative to the focal plane; and

(g) a control unit coupled to the detection unit and to the actuator, the control unit being responsive to said data representative of the received output radiation for determining the relative position of the addressed plane, and generating a focus error correction signal to operate the actuator accordingly.

2. The apparatus according to Claim 1, wherein the filter assembly comprises a spectral filter allowing the passage of the output radiation to the detector and preventing any other radiation spectrum from reaching the detector.

3. The apparatus according to Claim 1, wherein the filter assembly comprises a beam splitter for spatially separating the incident and output radiation spectrums and directing said output radiation to the detection unit.

4. The apparatus according to Claim 1, wherein said arrangement defining the at least two focal planes comprises an astigmatic element accommodated in the optical path of the separated output radiation.

5. The apparatus according to Claim 1, wherein

- said arrangement defining the at least two focal planes comprises an optical assembly for splitting the incident radiation into at least three spatially separated beams and focusing one of them onto said focal plane of the focusing optics and the at least two other beams on said at least two focal planes;
- said at least two focal planes are located below said focal plane of the focusing optics inside the carrier;
- said output radiation is composed of at least three spatially separated components; and
- said detection unit comprises three separate detectors, each for receiving a corresponding one of the output radiation components, the detectors being spaced from each other a certain predetermined distance along an axis of propagation of the output radiation towards the detection unit.

6. The apparatus according to Claim 5, wherein said optical assembly comprises a holographic plate accommodated in the optical path of the incident radiation upstream of the focusing optics.

7. The apparatus according to Claim 1, wherein said arrangement defining the at least two focal planes comprises a driver associated with the

focusing optics for providing continuous oscillation thereof along its optical axis.

8. The apparatus according to Claim 7, wherein said detection unit comprises an aperture accommodated in front of the radiation-sensitive surface, the diameter of the aperture being substantially equal to the dimensions of the recording region.

9. The apparatus according to Claim 7, and also comprising a modulation-sensitive electronics.

10. The apparatus according to Claim 1, wherein said beam splitting assembly comprises a dichroic mirror.

11. The apparatus according to Claim 1, wherein said material capable of generating the excited output radiation is a fluorescent material.

12. The apparatus according to Claim 11, wherein

- each of said recording regions comprises a material substantially reflective with respect to said incident radiation, the reflective material being located underneath said fluorescent material, so as to produce a reflected light component coming out of the information carrier;
- said detection unit comprises a first detector, defining said radiation-sensitive surface, and a second detector, the first and second detectors receiving, respectively, said output fluorescent radiation and said reflected radiation;
- said beam slitting assembly comprises a dichroic mirror for separating said fluorescent radiation and directing it onto the first detector, and a partially transparent mirror for separating said reflected radiation and directing it onto the second detector.

13. The apparatus according to Claim 12, wherein said control unit is coupled to the second detector.

14. The apparatus according to Claim 13, wherein said first detector receives the fluorescent radiation and generates data representative of the information stored in the information carrier.

15. The apparatus according to Claim 12, wherein the recording region also comprises a substantially absorbing material, located underneath the reflective material.

16. A pickup system for reading information stored in a three-dimensional information carrier, which is formed with a plurality of spaced-apart data regions, each surrounded by surrounding regions, wherein the data regions are made of a stack formed by an upper fluorescent material and a lower reflective material with respect to a predetermined incident radiation, thereby producing a first, fluorescent output radiation and a second, reflected output radiation, when interacting with said incident radiation, the surrounding regions being substantially optically transparent, the system comprising:

(i) an illumination unit generating said predetermined incident radiation which is directed onto an addressed plane inside the carrier;

(ii) a focusing optics accommodated in optical path of the incident and output radiation and defining a focal plane inside the carrier;

(iii) a first detection unit for receiving said first output radiation and generating data representative of the information stored in the carrier;

(iv) a first radiation splitting means for separating the first radiation and directing it to the first detection unit; and

(v) a second detection unit for receiving said second radiation and generating data representative thereof;

(vi) a second beam splitting means for separating said second output radiation and directing it to the second detection unit;

(vii) an actuator providing a relative displacement between the information carrier and the focusing optics along an optical axis thereof;

(viii) an arrangement defining at least two spaced-apart focal planes aligned in a preset relationship with said focal plane of the focusing

optics, said received second radiation being indicative of the relative location of the addressed plane relative to the focal plane; and

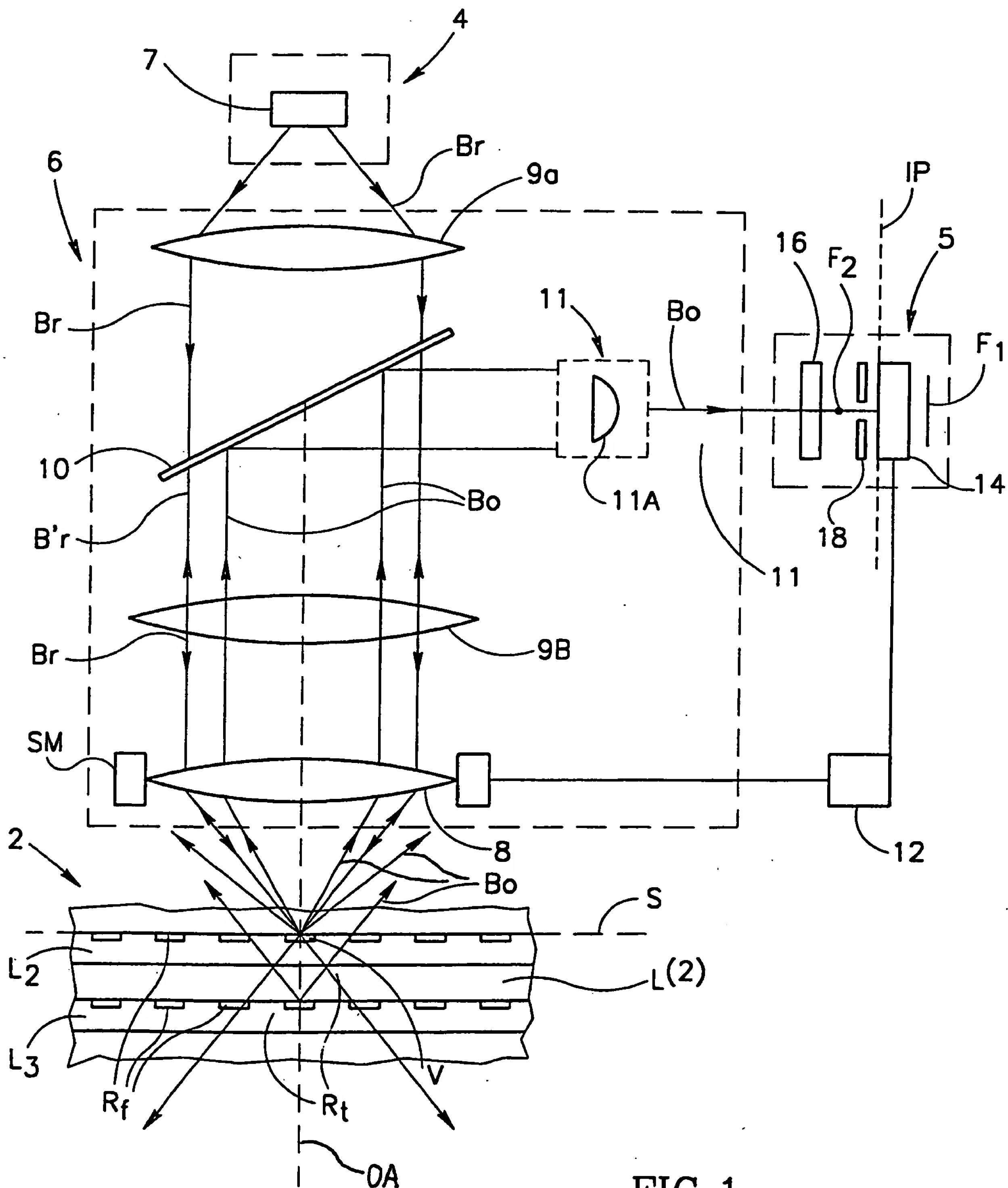
(ix) a control unit coupled to the second detection unit and to said actuator, the control unit being responsive to said data representative of the received second radiation for determining said relative position of the addressed plane, and generating a focus error correction signal to operate the actuator accordingly.

17. The system according to Claim 16, wherein said arrangement defining at least two spaced-apart focal planes comprises an astigmatic element accommodated in the optical path of the separated second radiation.

18. The system according to Claim 16, wherein said arrangement defining at least two spaced-apart focal planes comprises a driver associated with the focusing optics for providing oscillation thereof along its optical axis.

19. The system according to Claim 16, wherein

- said arrangement defining the at least two focal planes comprises an optical assembly for splitting the incident radiation into at least three spatially separated beams and focusing one of them onto said focal plane of the focusing optics and the at least two other beams on said at least two focal planes;
- said output reflected radiation is composed of at least three spatially separated reflected components; and
- said first detection unit comprises at least three detectors, each for receiving a corresponding one of said three radiation components, the detectors being spaced from each other a certain predetermined distance along an axis of propagation of the separated second output radiation.


4
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6
Br
9a
IP
16
F2
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11
Bo
F1
Br
10
B'r
11A
Bo
14
18
11
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9B
SM
8
12
2
Bo
S
L2
L(2)
L3
V
Rf
Rt
0A

FIG.1

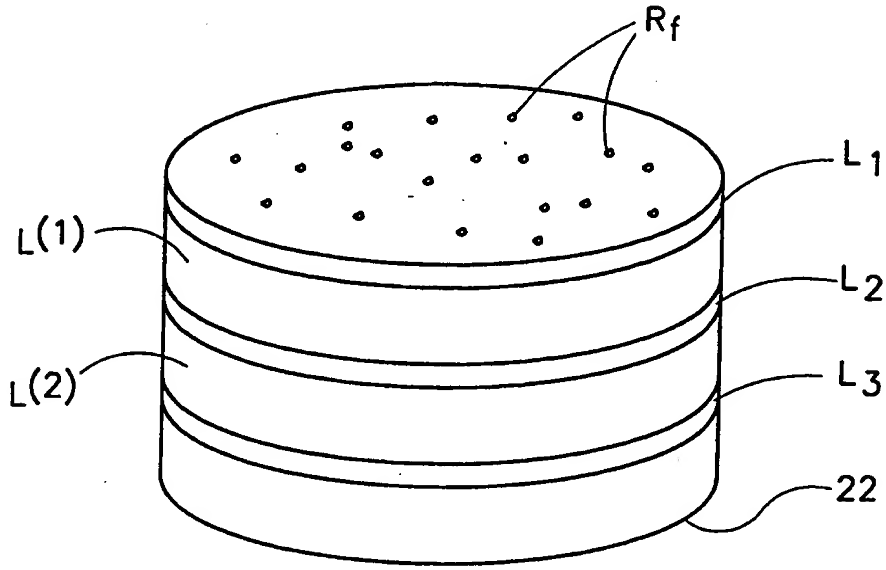


FIG.2A

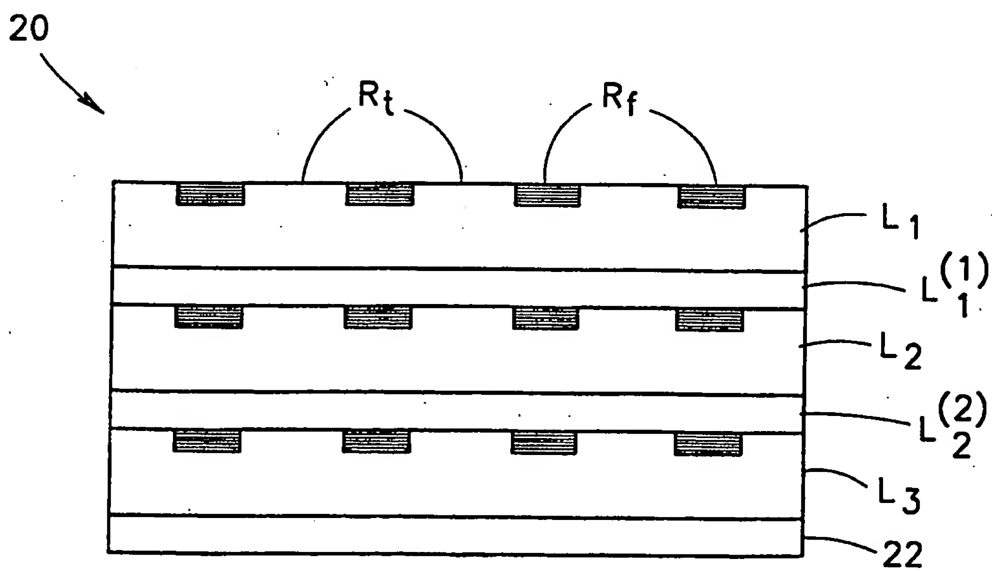


FIG.2B

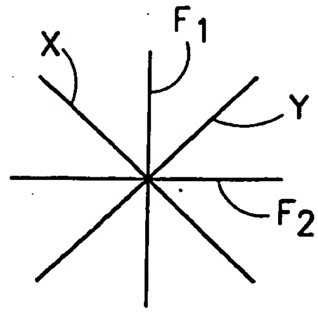


FIG.3A

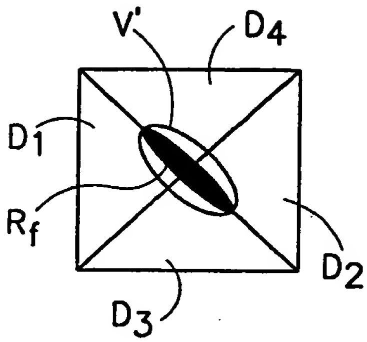


FIG.3B

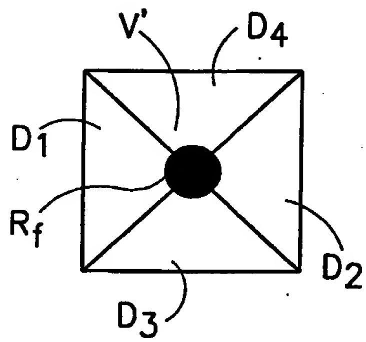


FIG.3C

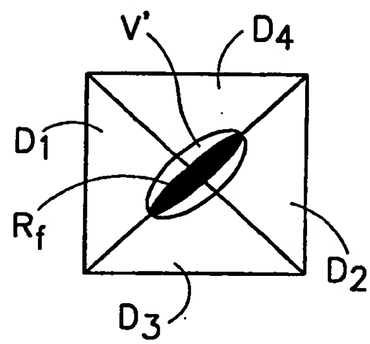


FIG.3D

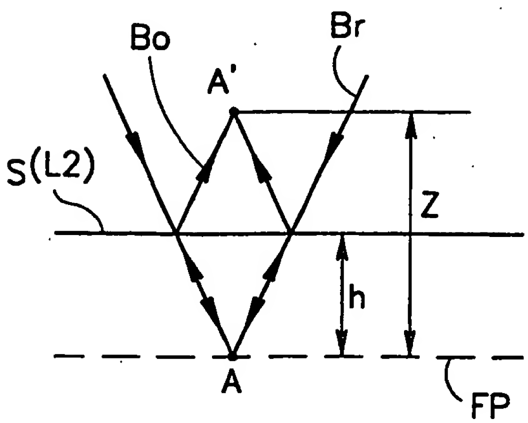


FIG.4A

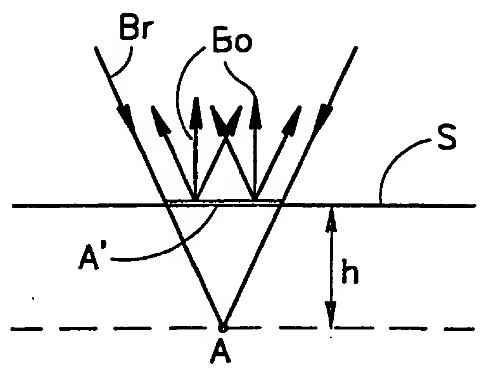
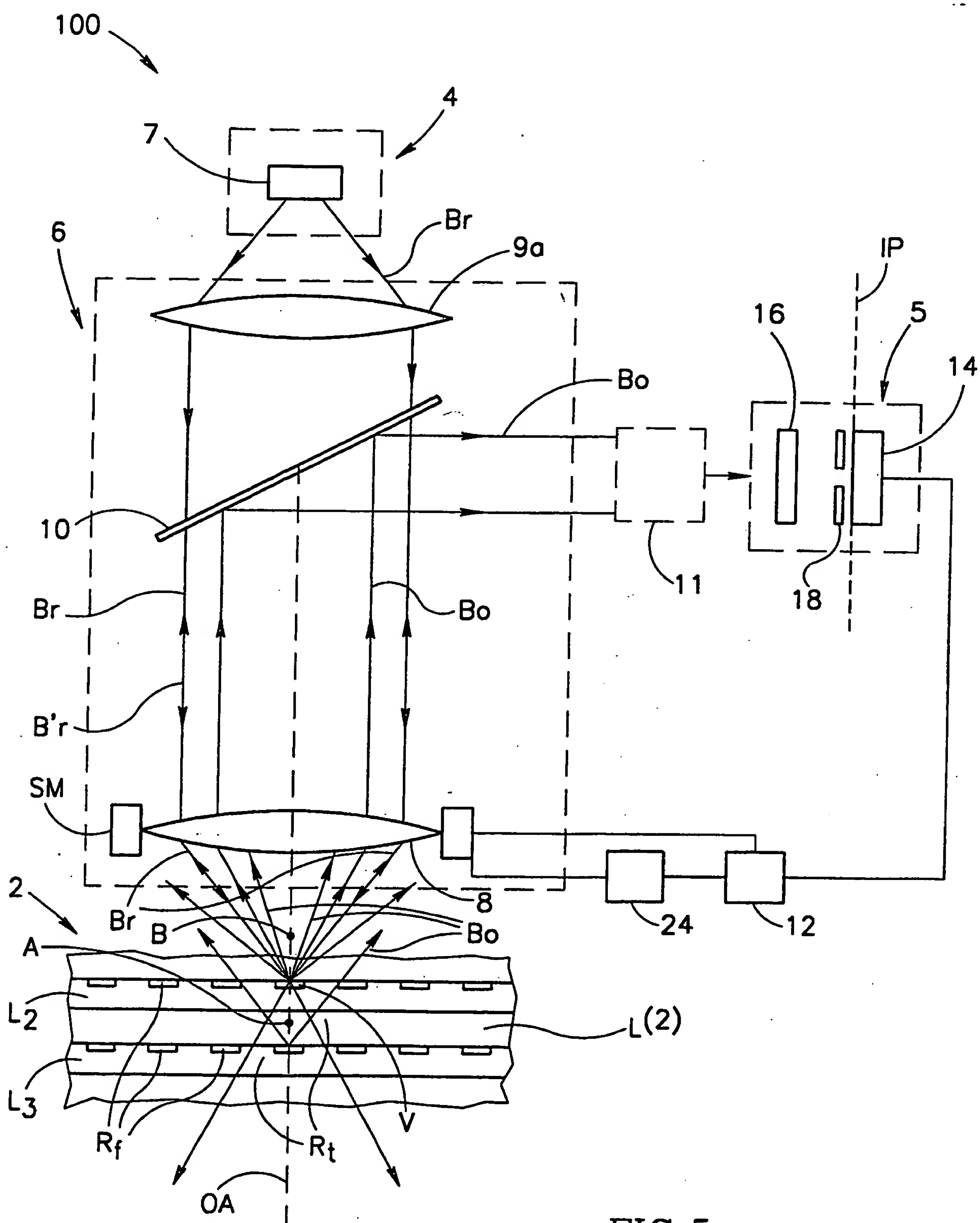


FIG.4B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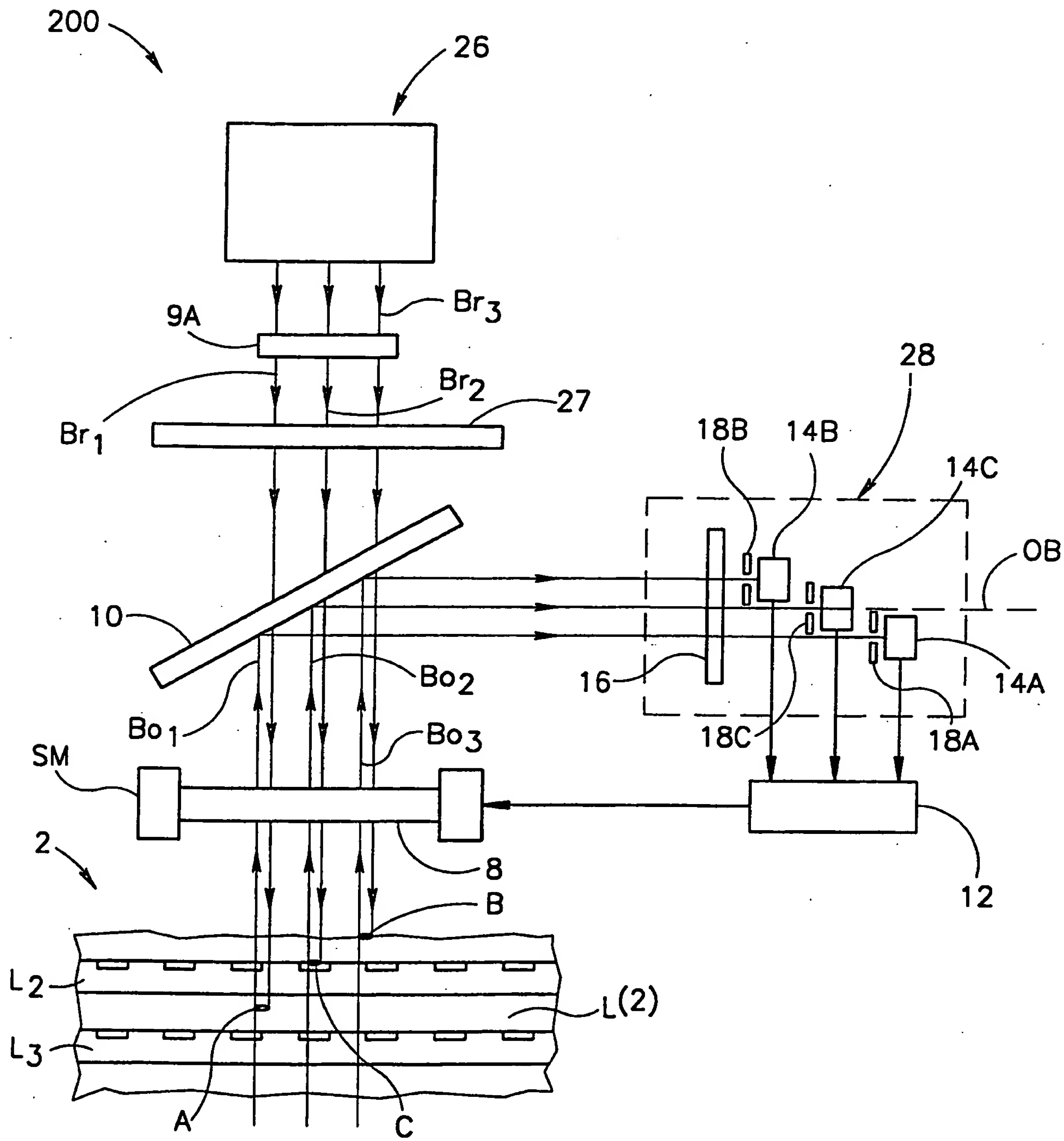
4
7
6
Br
9a
IP
16
5
14
Bo
10
11
18
Br
Bo
B'r
SM
2
Br
B
8
Bo
24
12
A
L2
L(2)
L3
Rf
Rt
V
OA

FIG.5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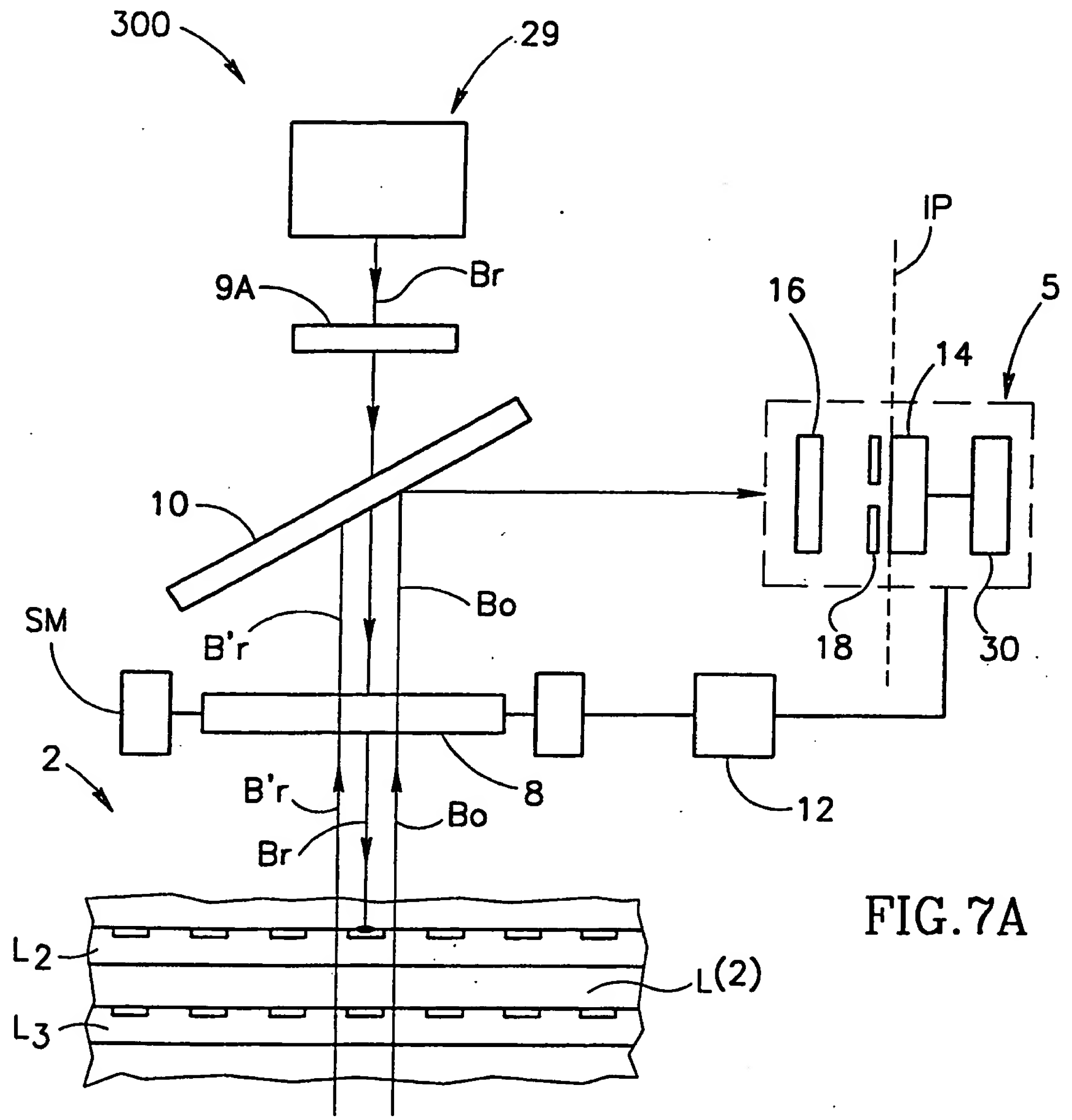
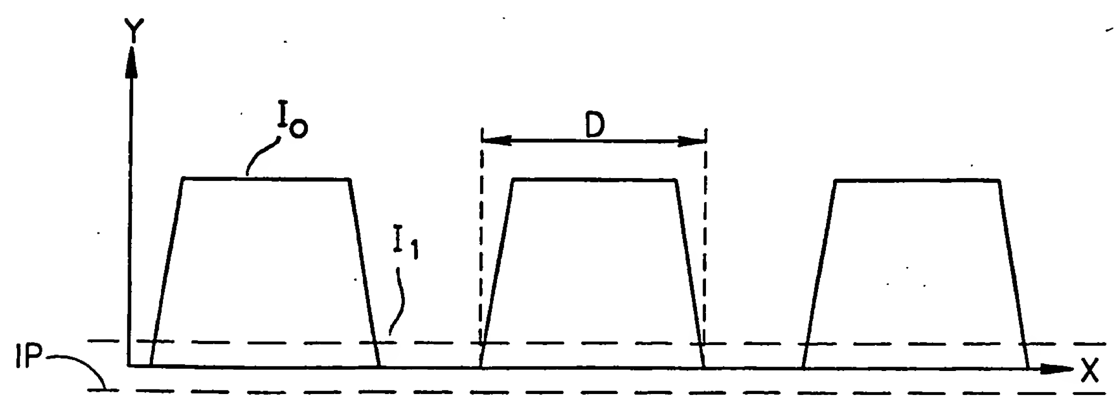
26
Br3
9A
Br2
27
Br1
28
18B
14B
14C
OB
10
Bo2
16
14A
Bo1
Bo3
18C
18A
SM
2
8
12
B
L2
L(2)
L3
A
C

FIG.6



300
29
9A
Br
IP
16
5
14
10
Bo
SM
B'r
18
30
2
B'r
8
12
Bo
Br
L_2
L(2)
L_3

FIG.7A



Y
I_o
D
I_1
IP
X

FIG.7B

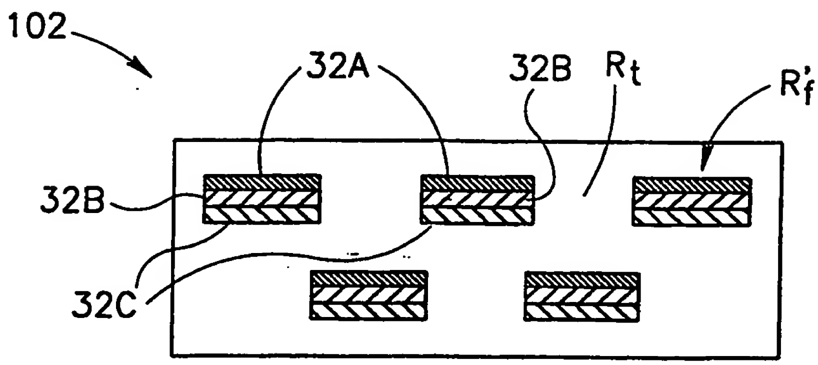

102
32A
32B
R_t
R'_f
32B
32C

FIG.8

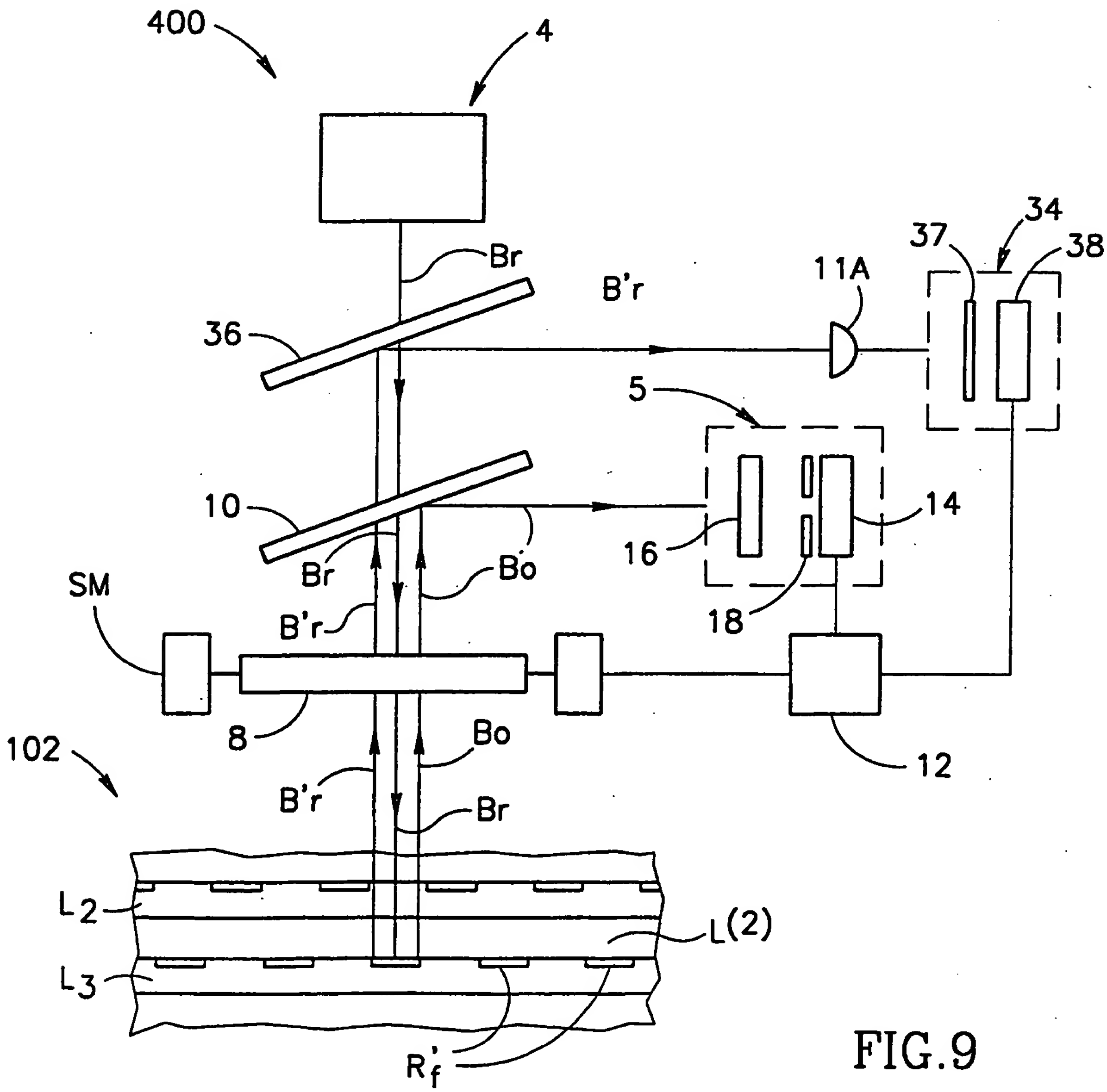

400
4
Br
B'r
36
11A
37
34
38
5
10
14
16
Br
Bo
18
SM
B'r
8
Bo
12
102
B'r
Br
L_2
$L(2)$
L_3
R'_f

FIG.9

INTERNATIONAL SEARCH REPORT

International Application No
PCT/IL 98/00538

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G11B7/09 G11B7/24

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G11B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 4 090 031 A (RUSSELL JAMES T) 16 May 1978 cited in the application see the whole document	1-3,11
Y	DE 44 44 988 A (WENDT ULRICH DR RER NAT HABIL) 20 June 1996 see the whole document	1-3,11
A	EP 0 354 601 A (PIONEER ELECTRONIC CORP) 14 February 1990 see the whole document	1-4,8, 10-14, 16,17

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
25 February 1999	04/03/1999

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx: 31 651 epo nl, Fax: (+31-70) 340-3016	Annibal, P

2

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/IL 98/00538

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